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ABSTRACT

Information on six research programs which studied eye movements during reading and evaluated aspects of PLATO-displayed reading instructional material is provided in this report. An analysis of eye movements of "competent" and "less competent" readers reading for general and detailed information showed many differences between them. One of the findings is that competent readers made fewer saccadic eye movements per line of print and spent less time on fixation pauses. In addition, when reading for detail, they did not change the size of the informational chunk taken in during each fixation pause but did increase the amount of time spent on such fixation pauses. Less competent readers decreased the informational chunk taken in per fixation but did not change the amount of time spent per fixation. Also reported are a pilot study concerning blink or saccad suppression of information, a study of eye movements as readers scan back from the end to the beginning of a new line, and the development of a procedure for measuring head movements. A study of informational chunking which investigated the effects of the wider angular distance of the PLATO display and typed materials suggests that a drop in efficiency of reading speed is noted when reading these compared to reading a printed book format. (MKM)

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ANNUAL REPORT
SEPTEMBER 30, 1975

Title: VISUAL SEARCH ACTIVITY: A tool for the evaluation and development of computer-assisted reading instructional programs.

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A. Project Objectives and Plan of Attack

The objectives of this proposal are:

I. To utilize information regarding eye movements during reading to:

a) make inferences about cognitive information processing engaged in by the reader;

b) identify aspects of "inefficient" reading; and

c) apply feedback technology to remediate such inefficiencies.

II. To evaluate aspects of PLATO displayed reading instructional material with respect to:

a) maintenance of the reader's interest in the material displayed;

b) physical display of information, such as orientation of the display panel, which may contribute to the user's feeling of "well-being" or the converse - "fatigue," and

c) evaluation of specific modules in current PLATO elementary reading program library.

B. The following studies have been completed. (These were partially or totally supported by Grant NSF-TIE-EPP75-51388, or its predecessor Grant EPP73-00156 A01.)

I. Reading for general information and detailed information: analysis of eye movements of "competent" and "less competent" readers performing these tasks.

II. Blink (saccad) suppression: a pilot study.

III. Development of "line-change" program.

IV. Development of acceptable procedures for measuring head movements during reading.

V. Informational chunking: Is it a function of print size or

informational content (PLATO vs. book display).

VI. Amount of information displayed, eye movements and comprehension: Preliminary study.

I. Dissertation by T. Goltz, entitled: "Characteristics of the Eye Movement Activity of Proficient Readers". This study falls under Ia of Project Objectives.

College students identified as competent and less competent on the basis of their performance on a standardized reading test were selected for participation in this study. One hundred volunteers were tested and the 20 highest and 20 lowest scorers invited to participate in this experiment. The experiment involved the recording of eye movements while subjects read 4 historical passages. Two were read under instructions to abstract only general information. The first of these two reading sessions was used to provide the reader with information about the level of generality or specificity of the questions asked. The second reading session only was used for the analysis. The same procedure was used on the selections for which subject has to abstract detailed information.

The results of this study.

a) Performance on the reading test is predictive of performance on reading different material (historical material used in the present study). Competent readers read faster than the less competent ones. This was true under both reading conditions used.

b) Significant differences in eye movement patterns were found for the two groups of subjects. Competent readers made fewer saccadic eye movements per line of print and spent less time on fixation pauses. For example, fixation pauses preceded by two and followed by two right going saccades (fixation pauses associated with "smooth" reading)

significantly differentiated the groups. Under reading for general information instructions fixation pause duration for these types of pauses was 190 msc for the competent readers and 240 msc for the less competent reader.

c) The effect of shifting from reading for general information to detailed information discriminated the groups.

1) Competent reader's strategy was to make no change in the number of R-R saccades per line read, and to increase fixation duration by approximately 9 msc (statistically reliable change). In other words, there was no change in the size of the informational chunk taken in during each fixation pause, but a significant increase in the amount of time spent on such fixation pauses.

2) Less competent readers, on the other hand, showed no change in the amount of time spent on each of these fixation pauses, but demonstrated significantly more fixation pauses per line read. Their strategy thus was to decrease the informational chunk taken in per fixation but not to change amount of time spent per fixation.

d) A detailed analysis of fixation pauses associated with regressive eye movements discriminated between the groups. Competent readers made regressive eye movements if the informational chunk taken in prior to the regressive eye movements was significantly greater than their normal R-R chunks.

Less competent readers, on the other hand, made regressive eye movements following a significant reduction in normal R-R chunks. We interpret these differences again as examples of different information processing strategies used by skilled as compared to less skilled readers. The skilled reader generally makes regressive eye movements to pick up information he has previously missed (because he attempted to take in

too large an informational chunk). The less skilled readers' regressions occur under conditions where he slows down because the material is becoming difficult for him. The less skilled reader is thus a much more cautious reader.

A number of other differences between groups were found, but those detailed above appear to be the most important.

II. Blink (saccad) suppression, a pilot study. This study was conducted by Mr. Roger Wibbenmeyer, in collaboration with Drs. Chen and Stern, and was an undergraduate senior honors thesis for Mr. Wibbenmeyer. This study falls under Ib of Project Objectives.

Saccad suppression refers to the suppression of visual information during and for a period preceding and following saccadic eye movements. Such suppression starts about 50 msc before saccad initiation and persists for 30-40 msc following termination of the saccad. It is thus believed to be a central nervous system mediated response rather than a peripheral one associated with the eye movement. Most such studies have used simple stimuli and the subject's response involved a binary decision - presence or absence of the stimulus.

The current study evaluated such suppression associated with eye blink onset (voluntary) and involved the making of a more complex decision. The stimuli presented were single digits (10). The viewer was instructed to a) report whether he had seen something (binary decision), and b) to identify the number he had seen if he reported seeing something.

Our study demonstrated that there is information suppression associated with the eye blink, which again starts about 50 msc before initiation of the blink. The suppression effect is more strongly seen under conditions where the subject has to identify the stimulus seen.

The nature of the eye blink associated with involuntary,

voluntary and defensive reflex blinking appears to be differentiable. Eye blink conditioners have discriminated between voluntary and involuntary blinks on the basis of response latency. Observations from our studies suggest that one can also distinguish between these two types of blinks on the basis of closure duration. Speed of eye closure during a blink appears to cleanly discriminate between reflex blinks and both voluntary and involuntary blinks. Closure duration of defensive reflex blinking (blast of air or nitrogen to eye) takes approximately 30-40 msc (F. K. Graham); while voluntary and involuntary blinks both take at least twice that long - 60-100 msc).

III. Development of "line-change" program. This study falls under Ib and Ic of Project Objectives.

In order to feed back information about inefficient "line-returns", i.e. return of the eye from the end of one line to the beginning of the next line, we had to:

a) evaluate the types of returns commonly made by efficient as well as inefficient readers; and

b) develop the necessary computer software to identify these line returns.

a) We have collected data on some 50 adolescent readers and 30 young adult readers to determine how they normally scan back from the end to the beginning of a new line.

Two types of "efficient" return patterns have been identified. The first involves a return utilizing a single saccadic movement, which takes approximately 60-100 msc, and is schematically depicted as pattern A below. (See also pictures #3 and 4).

The second pattern is characterized by a partial return

which sweeps the eye back approximately 80% of the (usual) total distance, fixates for a short period of time. Average fixation pause duration of 143 msc, where the average initial fixation on a line (LINE-R) or average forward going fixation (R-R) are consistently greater for every subject (Pattern B - below). (See also Picture #5).

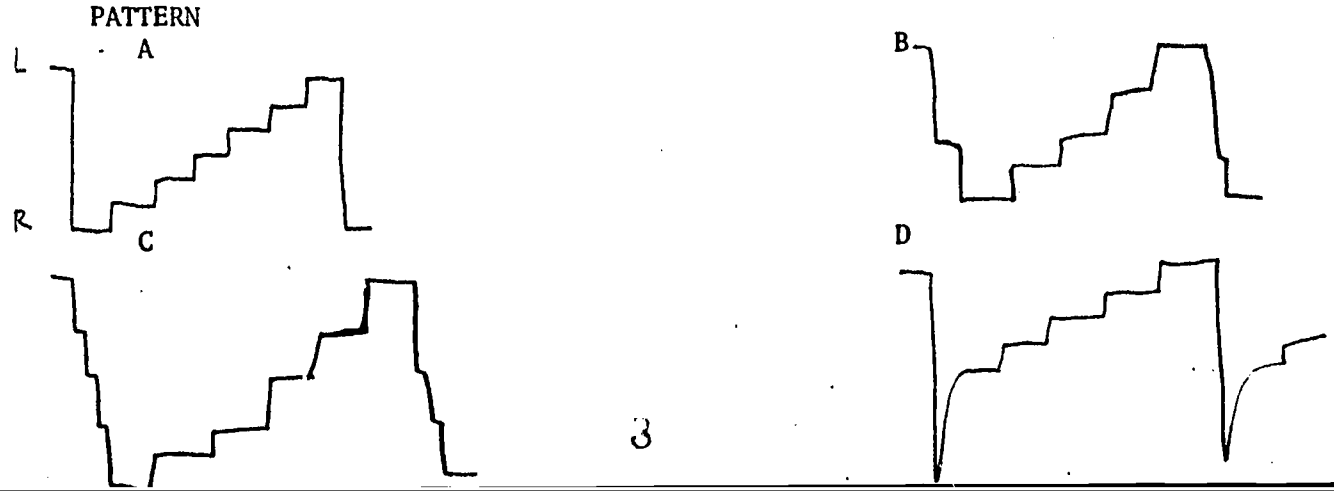
This pattern is identified as efficient if it occurs no more than on 50% of the line changes. What is assumed is that the efficient reader does not necessarily sweep back to the very beginning of a line of print, i.e. he can make an educated "guess" as to what was there from the material on the preceding line and the material he starts to look at on the new line. It is only under conditions where he cannot do such "cognitive interpolating" that he has to scan back further.

A variety of inefficient returns have been identified. They are all variants of two types:

1) multiple regressive saccades toreturn to the beginning of a line (see pattern C below; see also Picture #5) where the fixation pauses between regressions vary in duration, and

2) single or multiple regressive saccades in conjunction with a major head movement (see pattern D below).

Computer programs have been written which allow us to identify these various types of return sweeps so that we can now go to stage C and begin to use them in our feedback loop.



IV. Development of acceptable procedure for measuring head movements during reading. This study falls under Ib and Ic of Project Objectives.

Our concern is with the development of a procedure for measuring head movement that a) places no, or minimal, constraints on the reader; and b) is inexpensive.

We have attempted two procedures to date. The first utilized an accelerometer mounted on the earphone frames used to provide the PLATO terminal user with audio-information. A variety of placements and orientations were tried but the device proved to be relatively insensitive to picking up head movements associated with reading. The major problem was that background noise often obscured the head movement signal. We have considered attempting to develop a digital filter to extract the signal out of the noise by a) averaging head movements associated with line changes as picked up from the electrooculographic leads and using this averaged "evoked response" as a filter for subsequent head movement detection. Before pursuing this idea we planned to explore a number of other, simpler alternatives, all of which, however, place greater constraints on the reader. The one currently being tested utilizes a selsyn control transformer to convert rotational movements into voltages proportional to that movement. A shaft extends from the transformer to the subject's head and is mechanico-magnetically coupled to a pair of earmuffs worn by the subject. To stabilize the earmuff assembly, we place a velcro band around the head. Our problem is that the head movements made are quite small and unless the device used for picking them up is solidly anchored to the head the movements of interest are hidden in background noise.

V. Informational chunking: Is it a function of print size or informational content. This study falls under IIb of the Project Objectives.

Does the reader chunk information on the basis of maximum eye-span (i.e. the maximum linear distance in foveal vision, assuming that foveal viewing is necessary for reading) or is

informational content of the material viewed an equally important component? The Goltz study (I above) suggests that informational chunking is dependent on:

a) purpose of reading (general vs. detailed information); and

b) reading skill level.

Skilled readers do not alter size of informational chunk as they shift from general to detailed information abstraction, while less skilled readers do alter chunk size.

The PLATO displayed text material, as well as normally typed material, is less "efficiently" spaced than similar material in printed format, i.e. a line of print which takes up 12.5 cm of space will take up 18 cm on the PLATO display and in typed format. Does the wider angular distance of the PLATO display and typed material affect informational chunking and speed of reading? Does the PLATO display lead to less efficient reading performance than the typewritten display?

To answer these questions we have to date studied 11 subjects who read textual material displayed a) in a book, b) the same material typed, and c) the same material displayed on PLATO. We have observed that the angle subtended by PLATO and typed text reading is consistently greater than that utilized in reading the same material, when it is presented either as typed text or PLATO displayed text.

(Full line width)	$\bar{X}$	"t"	p
Book	14.34°		
		8.96	.001
Typed	21.34°		
		.60	NS
PLATO	22.00°		

Thus if linear distance is an important component in informational chunking, we should find that for both typed and PLATO displayed text the reader makes more fixation pauses per line read. To evaluate this, and other possibilities, we utilized our reading analysis program to evaluate differences in eye

movements as a function of type of display. The results demonstrate no differences in ability to answer questions about material read as a function of display mode. Average time to read a line (based on the analysis of approximately 100 lines read under each condition) significantly discriminated the book from the other two conditions. Average time (of medians) to read a book line (B) was 1.84 sec; for reading an equivalent content typed (T) and PLATO displayed line (P) 1.96 and 2.03 seconds, respectively. (Though, on an absolute basis these differences are small, they reflect a considerable decrease in reading efficiency d drop of about 6% for the typed and 10% for the PLATO displayed text). Both of these values are significantly different from the text reading condition, but not different from each other. The analysis of variance of median time per line under the three conditions was significant beyond the .01 level. The Newman-Keuls test obtained differences between the B and T material ($p < .05$) and between the B and P displayed material ($p < .01$).

What aspect of reading performance accounts for these differences? An obvious culprit is time taken to make saccadic eye movements, since the eye has to travel further in the PLATO and typed text conditions, as compared to the printed text. This variable apparently does not contribute much to the differential effects. We say apparently because the accuracy of resolution used in our analysis is $\pm$ 10 msc, and we did not attempt to control, in an absolute sense, for head position with respect to the displayed material. Within these constraints, we do not, for example, find consistent differences in amount of time taken by the eye to traverse from the end of the line to the beginning of a new line. Though not statistically reliable, we do find that in the PLATO and typed condition the modal number of fixation pauses (associated with forward moving saccades) increases. The increase is, however, considerably smaller than would be suggested from an extrapolation based on the linear distance encompassed by a line of print under these conditions.

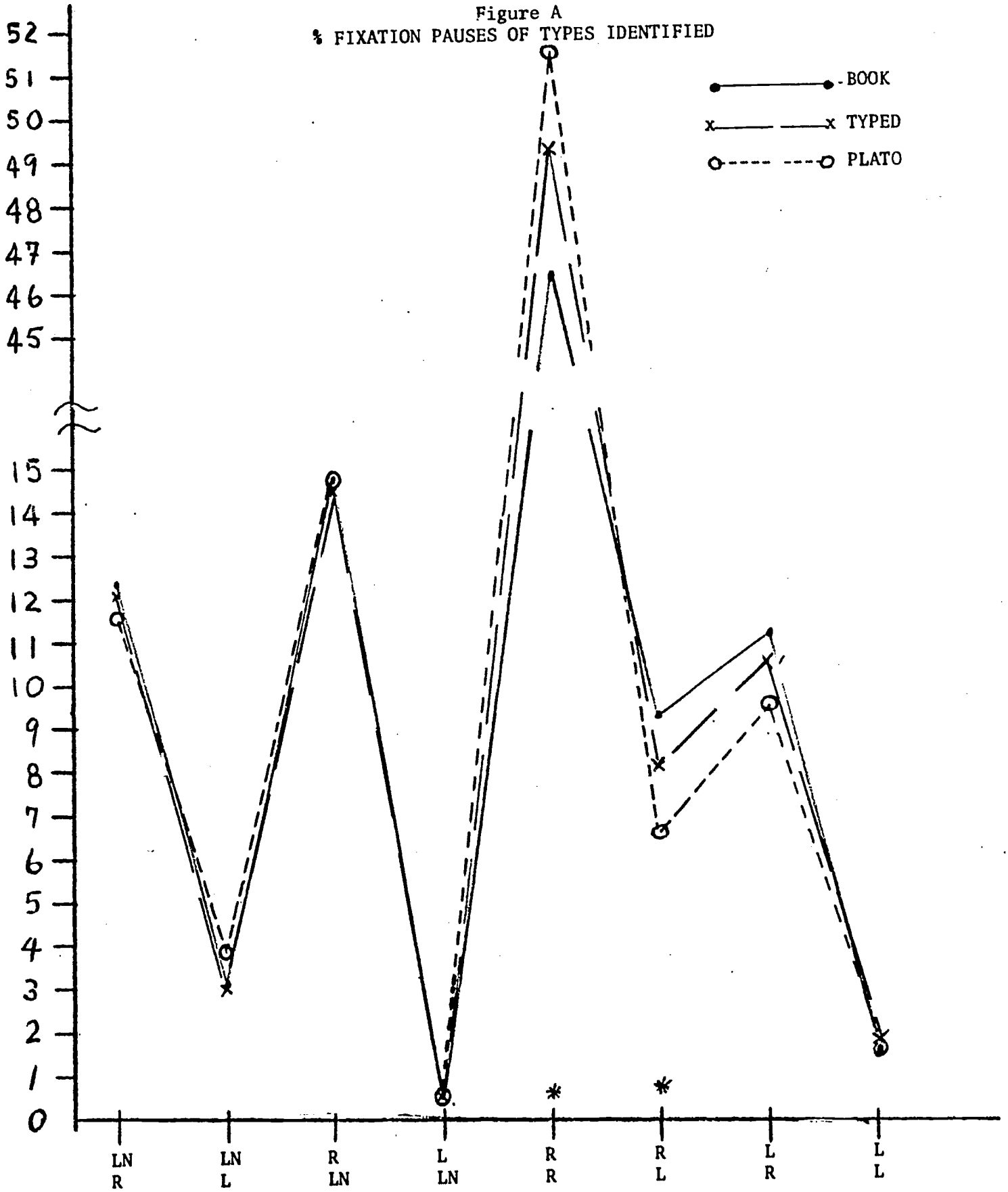
Evaluating the duration of various types of fixation pauses we find that the first fixation pause on a line of print (LN-R) is significantly shorter for the B and T as compared to the P condition (ANOVA [2, 18] F 7.47 $p < .01$). Mean of median LINE-R fixation pauses is 328 msc, 338 msc, 370 msc, for the B, T and P displayed material, respectively. The P condition produced significantly longer fixation durations of this type ($p < .05$) when compared with the B and T conditions. R-R fixation showed a similar ordering of fixation pause durations, the results were, however, not statistically significant (244; 251; 256 msc durations for B, T, and P conditions, respectively). Similar effects are seen for most other fixation pause duration conditions, with the order being B material having shortest fixation pause durations and P displayed material the longest. None of them are, however, statistically reliable (F test).

A second analysis of the data evaluated the proportion of specific types of fixation pauses as a function of reading condition. In all cases and for all subjects the total number of fixation pauses entering into this evaluation ranged between 503 at the lower end and 822 fixation pauses per condition at the upper end. The percentage values thus should be relatively stable. Most of the fixation pauses were, of course, R-R type, i.e., fixation pauses preceded and followed by a right going saccade. The percentage for the B, T and P conditions, respectively, were 46.5%, 49.4%, and 51.6%.

Figure A about here

These differences are significant at the $p < .01$ level with the B and P conditions differing from each other at the .01 level and the B and T conditions significant at the .05 level. Percentage of fixation pauses preceding regressive eye movements (R-L) also significantly discriminated between conditions ($p < .01$), the B condition producing the greatest percentage of this type of fixation pause (9.3%); the T condition an intermediate value (8.2%) and the P condition the smallest percentage of such fixation pauses (6.6%).

Figure A
% FIXATION PAUSES OF TYPES IDENTIFIED



The results of these analyses thus suggest that text displayed in printed format is read more efficiently than the same text displayed either as typed material or on a PLATO terminal. Relative to printed text the drop in efficiency is of the order of 6 and 10% respectively for the two conditions. By efficiency we here mean reading speed since comprehension was equivalent for the three reading conditions. Variables accounting for the less efficient reading under these two conditions are

1) The first fixation on a line of text is significantly longer for the P than the other conditions.

2) Though not characteristic of all subjects the incidence of LINE-L type eye movements to get back to the beginning of a line are more frequent than under the other two conditions (5 of 10 subjects had at least twice as many LINE-L changes under P than B condition).

3) Though not reliably different average fixation pauses for all types of fixations are longer under the P and T conditions (as compared to B presentation).

4) Under the P and T conditions readers appear to be somewhat more cautious in that the proportion of fixation pauses preceded and followed by (R-R) right going fixations is significantly greater when compared to the B condition; and the proportion of fixation pauses associated with regressions (R-L) are significantly fewer.

It should be emphasized that these are post-hoc rationalizations of the data and will be tested as hypotheses in future studies.

V. Amount of information displayed, eye movements, and comprehension: preliminary study. This study falls under Ib of Project Objectives.

Our concern in this study is with the question of how much "information" the reader attends to while reading. How much "peripheral" information (defined as that information peripheral to making semantic sense out of the material being systematically viewed) does the competent reader utilize. There is some literature which suggests that he abstracts rudimentary information with "peripheral" vision a) about material on the line he is reading and to the right of where he is fixating (Hochberg); b) on the line below or above that which he is reading (Willows); and c) abstracts "spatial" information, i.e. where on the page particular material is found, and where in the text particular material is placed (Rothkopf).

The present experiment was designed to ask whether the reasonably competent reader limits his information intake to the line he is "reading" or does he concurrently take in information occurring elsewhere in the visual display. The PLATO system was programmed to a) take stored text and scramble same so that word spacing and punctuation were retained, and general boundary format of words was maintained (example: hare would read bovc), b) allow such scrambled text to be unscrambled and rescrambled upon external command (from our PDP-11 computer), c) allow for variable number of lines of text to be unscrambled. The PDP-11 computer was programmed to identify eye movements associated with line change and to transmit a signal to the PLATO system to unscramble a new line and rescramble an earlier line. (Specifically, at a point in time when the eye had returned half-way to the beginning of the new line (50 msc) a signal was transmitted to PLATO to unscramble the next line and upon completion of that task to rescramble an earlier line. Transmission over the phone line is at 1200 baud or 180 characters per second. Each line was composed of approximately 60 characters. Thus total time to unscramble line was 330 msc. Another

330 msc was taken up in rescrambling an earlier line).

Twenty subjects participated in an experiment where they read 4 pages of text under each of 3 conditions, single line unscrambled, two lines and 4 lines unscrambled. Because of a variety of technical problems (principally dealing with transmission errors in PLATO display - since corrected), data for only 8 subjects could be analyzed. They were instructed to read so that they could later answer questions about the material. Many subjects complained about the single line unscrambled text display because they had to wait at the beginning of the line for text to be unscrambled. The most common comment was that it interfered with their reading rhythm, a second, equally frequent comment indicated a feeling of distraction produced by the unscrambling and scrambling of text. Results indicate that single line presentation leads to slower reading ($p<.05$) than is true of the 2 line display. Subjects under the single line condition utilized more fixation pauses to read a line of print than was true for either the 2 or 4 line condition ($p<.05$); demonstrated a tendency to make more regressions per line (F significant$<.10$). Fixation pause duration did not change significantly for any type of fixation pause evaluated (R-Ln; R-R; R-L; L-R). Saccad amplitude did discriminate between the single vs multiple line text display. This effect was seen only for forward going saccades (R-Ln; R-R) but not for saccades associated with regressive eye movements (R-L; R-L; L-R; L-R).

The data thus does demonstrate that reasonably competent readers make use of information occurring "around" the line of print to which he is attending. Specifically, we find that the less material available to the reader, the more mechanical and less efficient the reading process. The most obvious and interesting change dealt with saccad amplitude. As less information was made available to the reader, the average amplitude of saccades associated with efficient reading (forward going saccades) decreased. Interestingly, saccades associated with regressive eye

movements do not demonstrate this phenomenon.

Most of the problems associated with the loss of data for many subjects have been resolved. Many of our problems were attributable to low signal to noise ratio in our transmission line which, after many trials and tribulations with a recalcitrant telephone company, have been resolved.

C. Findings:

FIG. 1 Displays subject sitting in front of PLATO display with eyemovement amplifiers to right of the terminal. Subject is wired for the recording of eye movements in the horizontal and vertical plane.

FIG. 2 Close-up of subject wired for eye movement recording. PLATO terminal and eye movement amplifiers in background.

FIG. 3 Display of digitized horizontal eye movement information during reading. Time moves from left to right. The large amplitude downward shifts are associated with the eye shifting from the end to the beginning of a new line. Three line changes are depicted. Sampling period is 10 msc.

FIG. 4 Display of computer processed eye movement information of a "computer" reader. Saccadic eye movements are identified by dot intensification and direction is identified as: U - for right moving saccades; and L - for saccades to the left associated with a line change. This display demonstrates "idealized" reading, the reader making no regressions. This picture can be contrasted with Figure #5.

FIG. 5 Depicts a less competent reader. He returns from the end of a line to the beginning of a new line by making a series D (= left going saccades) eye movements. These sum up to be large enough for them to be identified as a line change. On the next line (to the right of the vertical line at top of display), he makes one regressive eye movement during reading.

D. Publications:

In preparation:

Goltz, Theodore H., "Characteristics of the Eye Movement Activity of Proficient Readers". Doctoral Dissertation, Washington University, 1975.

Wibbenmeyer, Roger, "Elevation of Visual Threshold Prior to the Onset of the Eyeblink". An Honors Thesis, Washington University, 1975.